

2-15-91  
E5973

NASA Technical Memorandum 103735

# The Effect of the Low Earth Orbit Environment on Space Solar Cells

David J. Brinker  
*Lewis Research Center  
Cleveland, Ohio*

John R. Hickey  
*Eppley Laboratory, Inc.  
Newport, Rhode Island*

Donald K. Brasted  
*Lewis Research Center  
Cleveland, Ohio*

Prepared for the  
5th International Photovoltaic Science and Engineering Conference (PVSEC-5)  
cosponsored by the Japan Society of Applied Physics, the Institute of Electrical  
Engineers of Japan, and the Foundation for the Advancement of  
International Science  
Kyoto, Japan, November 26-30, 1990





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David J. Brinker  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

John R. Hickey  
Eppley Laboratory, Inc.  
Newport, Rhode Island

Donald K. Brasted  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

## SUMMARY

The results of a space flight experiment designed to provide reference cell standards for photovoltaic measurements as well as to investigate the solar spectrum and the effect of long term exposure of solar cells to the space environment are presented. This experiment, the Advanced Photovoltaic Experiment, was launched in to low Earth orbit as part of the Long Duration Exposure Facility in 1984 and retrieved 69 months later. APEX contained over 150 solar cells of a wide variety of materials, designs and coverglasses. Data on cell performance was recorded for the first year-on-orbit.

## INTRODUCTION

The Advanced Photovoltaic Experiment (APEX) is a flight experiment designed to provide reference solar cell standards for laboratory measurements as well as to investigate the solar spectrum and the effect of long term exposure of solar cells to the space environment. It was launched into low Earth orbit in April 1984 as part of the Long Duration Exposure Facility (LDEF). Although the experiment was designed for an on-orbit lifetime of 12 months, retrieval was delayed until January 1990. This unplanned sixfold increase in flight time has resulted in the inability to meet some of the original mission objectives, but will yield data concerning the survivability of solar cells in low Earth orbit.

This paper will discuss the objectives of the experiment, the design to achieve these objectives, and the sensors and cells selected for flight. A preliminary analysis of the flight data and the physical changes will be included.

## EXPERIMENTAL OBJECTIVE AND DESIGN

The objectives of APEX were threefold. The first was to determine the performance of advanced solar cells in the low Earth orbit environment. This was to be accomplished by the measurement and recording of the short-circuit current of 120 cells whenever the Sun angle was most optimum. The current-voltage characteristic of another 16 cells was determined at the same time.

The second was to calibrate reference cells for use as intensity standards in laboratory solar simulators. The daily determination of short-circuit current, and the concomitant solar intensity and Sun angle data, of the 120  $I_{sc}$  cells throughout the planned duration of the flight would satisfy the requirements of this objective.

The measurement of the energy distribution in the extraterrestrial solar spectrum was the final objective. Three instruments were utilized for this purpose. An absolute cavity radiometer measured the total solar irradiance when illuminated solar cell performance was being recorded. The measure of the broad band solar spectrum was obtained using a dichroic mirror to divide the spectrum into two roughly equal parts. Silicon cells were used as sensors. Sixteen narrow bandpass filters coupled with silicon solar cell detectors were used to measure the solar spectrum over a wavelength span of 0.3 to 1.1  $\mu\text{m}$ . These filters could then be used for the calibration of a laboratory spectral response system.

LDEF, the host satellite, was designed to provide economical access to low Earth orbit for experiments which did not require telemetry or large amounts of electrical power. The LDEF Project was initiated in 1974 by NASA Langley to utilize the two-way transportation capability of the Space Shuttle. An announcement of opportunity was made in 1976 and a project plan for a photovoltaic experiment was written by the NASA Lewis Research Center. The advanced photovoltaic experiment was fabricated by the Eppley Laboratories, Inc. of Newport, RI. Figure 1 shows APEX just prior to integration with LDEF.

Project constraints required that APEX was to be completely self-contained in terms of control, data acquisition and storage and power. To attain maximum accuracy in cell calibration, it was desirable to minimize reflected radiation reaching the cells. Since relative solar azimuth varies with time in orbit and the minimum relative solar elevation occurs at the terminator crossing, a slat-slot approach was used for the cell field-of-view (FOV) design. A cell's FOV is therefore small in the elevation axis and large in the cross-axis. The 12 in. deep, full size (50 by 34 in.) tray was divided into three bays. The smaller cells, typically 2  $\text{cm}^2$  or 2 by 4 cm and requiring less depth than larger cells to attain the proper FOV, are mounted in bays 1 and 3. The larger area cells, requiring a greater depth, are mounted in the central bay 2. The shallowness of bays 1 and 3 provides room for the electronic systems. Baffles located between the rows of cells further minimize reflection. The baffles and the underside and upper surfaces of the FOV plates were painted with Chemglaze Z-306 matte black paint.

The solar cells selected for APEX included silicon and gallium arsenide cells with a wide variety of coverglasses and adhesives. Cell size ranged from 2 by 2 cm to 5.9 by 5.9 cm. Aircraft, balloon and rocket standards were included in the cells provided by nine institutions.

An Eppley H-F cavity radiometer can be seen in figure 1 as the round object in the upper part of the tray. Next to it is the digital solar angle sensor which measures Sun angle on two orthogonal axes and enables optimal conditions to be selected for performance measurement. To the right of the DSAS is the dichroic mirror with its two silicon cell sensors. In the row below these instruments are the narrow bandpass filters which are mechanically clamped over the silicon cell sensors.



The solar cells were mounted on removable aluminum plates, either singly or in pairs of smaller cells. For the 120  $I_{sc}$  samples, a precision resistor was wired across the cell. Short-circuit current was easily determined by measuring the analog voltage across the resistor. The short-circuit current of the sensors cells in the dichroic mirror instrument and under the bandpass filters was determined in the same manner. The 16 I-V cells had a six point characteristic measured by the switching of a number of predetermined load resistors across the cell.

The temperature of most of the cells as well as several locations on the tray were measured using 128 thermistors. They were bonded into a slot machine in the aluminum cell mounting plate, directly beneath the cell.

The experiment was designed to acquire performance data from the cell samples and associated instruments once per 24 hr period, on those days when the orbital conditions allowed such a measurement. Every 8 days a night scan was conducted, which enabled calibration of the instrumentation and a measure of the dark currents of the solar cells. This data was also recorded. Two separate electronics systems provided this capability. One, the Langley provided Electronics Power and Data System (EPDS), provided timing signals, data storage, power to the experiment and an interface to LDEF for initiation. The other, the APEX Data Acquisition System performed the primary control and data acquisition functions. This system was designed and built by Gulton Industries under subcontract to Eppley Labs. The most optimum Sun angle conditions for each day scan were insured by the DSAS.

After data acquisition was completed the data was transferred through the EPDS to the flight recorder. The data words were handled in a 12 bit format. Because the capacity of the EPDS was 4096 words per interrogation and that of the APEX electronics was 8000 words, the data was transferred in two scans, 12 hr apart. Upon receipt of the data, the EPDS wrote the data to the tape three times for redundancy.

After fabrication and functional testing of APEX was completed at Eppley Labs, the experiment was shipped to NASA Lewis for thermal-vacuum and vibration qualification testing. Final verification of system operation was performed at the Kennedy Space Center during November 1983 prior to integration with LDEF.

LDEF is a 12-sided cylinder 30 ft long and 14 ft in diameter. Experimental trays, 34 in. wide by 50 in. long, were bolted onto the 12 sides, with 34 in.<sup>2</sup> trays attached to both ends. The satellite was placed into a circular orbit of 256 nmi altitude with an inclination of 28.5°. The satellite was gravity-gradient-stabilized with one end of the cylinder always facing the Earth and one of the 12 sides, designated row 9 always perpendicular to and facing the direction of orbital motion. It was this row, the leading edge, which saw the full effect of the ram, including atomic oxygen flux and micro-meteoroid and debris. APEX, designated experiment S0014, occupied position E9, the second experimental tray from the space end on the leading edge. A photograph of LDEF, moments after deployment by the Challenger is shown in figure 2. APEX is visible as a black tray on the same row as the two trunnions with skid plates for fastening LDEF to the Shuttle payload bay.

The retrieval of LDEF was planned for February 1985. However, changes in payload manifest priorities delayed retrieval. The loss of the Challenger

and the resulting hiatus in the Shuttle program caused considerable additional delay. The altitude of LDEF continued to decay, exacerbated by the near record solar activity of solar cycle 22. When retrieved by the Columbia on January 12, 1990, the altitude of LDEF was about 180 nmi.

During deintegration at the Kennedy Space Center photographic, radiation, and thermal surveys were conducted. Batteries were removed and their charge state measured. A detailed survey of micrometeoroid and debris impacts was also conducted. The experiment was then returned to NASA Lewis. The recorder was removed and delivered to its manufacturer, Lockheed Electronics Company, for processing and data transcription. The flight data has since been loaded in to the Lewis Research Center's scientific VAX cluster for analysis.

## EXPERIMENTAL RESULTS

After experiencing the full effects of the LEO environment for nearly 6 years, many changes are readily apparent. The black paint has been thinned from the upper surface of the field-of-view plates, exposing the primer. The top plate of the DSAS, originally bare aluminum, is now gold in color. Contamination of a yet unknown composition and origin is found over much of APEX, as well as LDEF itself. A yellow-gold film is particularly evident on cells and mounting plates in the two rows nearest the space end of the tray. Discoloration is also seen on the baffle plates and the underside of the field-of-view plates.

Hundreds of impacts from micrometeoroids and debris are evident, the majority smaller than 0.5 mm in diameter. The largest crater has a diameter of about 2 mm. Among the impacted surfaces are the glass aperture of the DSAS, one of the bandpass filters and a number of solar cells. Damage to the cells includes cratered and cracked coverglasses, craters extending into the cell itself, and in one case, a small portion of a silicon cell and coverglass was removed as the particle continued into the aluminum substrate.

Analysis of the flight data indicates that all of the electronic systems, sensor and instruments functioned as designed. 358 days of photovoltaic data has been obtained. The Gulton system, providing this data, presumably ceased operation when its batteries discharged to below a threshold level, as the two 28 V batteries powering the Gulton system were totally discharged when they were removed.

Values of cell currents, voltage calibration data, the cavity radiometer signals are all within nominal, expected values. Detailed analysis of the data from the nearly 300 discrete signal channels has begun and is expected to continue into the foreseeable future. Removal and testing of individual cells will begin when flight data analysis is completed and no further systems check are required.

## CONCLUSION

The Advanced Photovoltaic Experiment, a flight experiment which measured the performance and durability of solar cells in low Earth orbit has been retrieved after nearly 6 years in LEO. The experiment performed as designed

and has returned data covering the first 12 months in orbit. Detailed analysis of the flight data is continuing and will be reported at the earliest opportunity. In-depth studies of the electrical and material changes in the individual solar cells will then be conducted.



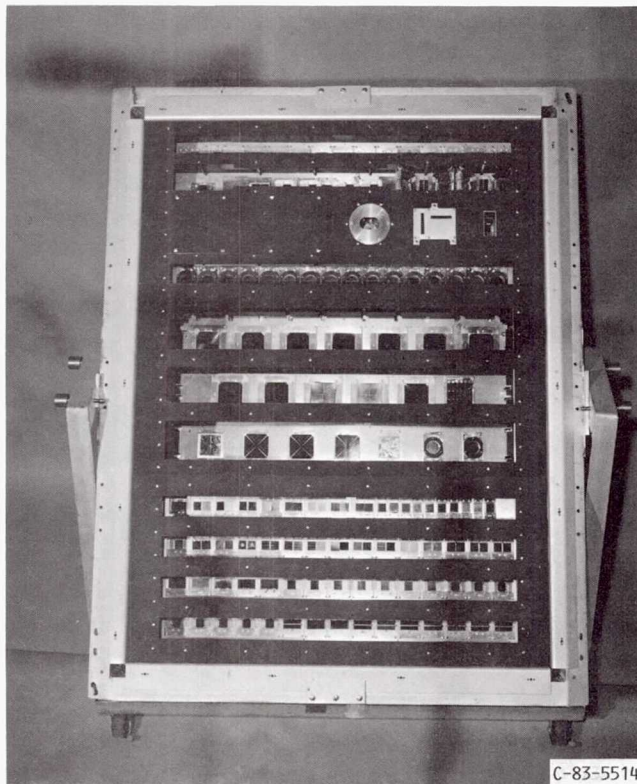


FIGURE 1. - APEX PRIOR TO FLIGHT.



FIGURE 2. - LDEF IMMEDIATELY AFTER DEPLOYMENT.

# Report Documentation Page

1. Report No. NASA TM-103735		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle The Effect of the Low Earth Orbit Environment on Space Solar Cells				5. Report Date	
				6. Performing Organization Code	
7. Author(s) David J. Brinker, John R. Hickey, and Donald K. Brasted				8. Performing Organization Report No. E-5973	
				10. Work Unit No. 506-41-11	
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001				14. Sponsoring Agency Code	
15. Supplementary Notes  Prepared for the 5th International Photovoltaic Science and Engineering Conference (PVSEC-5) cosponsored by the Japan Society of Applied Physics, the Institute of Electrical Engineers of Japan, and the Foundation for the Advancement of International Science, Kyoto, Japan, November 26-30, 1990. David J. Brinker, NASA Lewis Research Center; John R. Hickey, Eppley Laboratory, Inc., Newport, Rhode Island 02840; Donald K. Brasted NASA Lewis Research Center. Responsible person, David J. Brinker, (216) 433-2236.					
16. Abstract  In this paper we report the results of a space flight experiment designed to provide reference cell standards for photovoltaic measurements as well as to investigate the solar spectrum and the effect of long term exposure of solar cells to the space environment. This experiment, the Advanced Photovoltaic Experiment (APEX), was launched in to low Earth orbit as part of the Long Duration Exposure Facility (LDEF) in 1984. Although the planned duration of the flight was 11 months, its retrieval was delayed until January of this year, after nearly 6 years in orbit. APEX contained over 150 solar cell samples of a wide variety of materials, designs and coverglasses. Short-circuit current values were recorded for the first year on-orbit for 120 cells with the current-voltage characteristic measured for another 16. The spectral content of the solar insolation was measured using bandpass filters and silicon cell sensors, while the total solar insolation level was determined with a cavity radiometer. Positioned on the leading edge of the satellite, APEX was exposed to the largest possible dosage of atomic oxygen, micrometeoroid and debris and ultraviolet radiation. Significant physical changes are readily apparent, including erosion of front surface paint, contamination from yet unknown sources and cratering of the solar cells and coverglasses from micrometeoroids and debris. In the full paper we will present and compare the performance of the solar cells as measured and recorded for the first 358 days of flight. A comparison of cell pre-flight and post-flight performance (as measured in a laboratory solar simulator) will also be presented in order to determine the durability of the cells and effect of long term exposure to the low Earth orbit environment. The nature of and the effect of contamination on solar cell performance will also be discussed.					
17. Key Words (Suggested by Author(s)) Long Duration Exposure Facility (LDEF) Space solar cells Photovoltaics			18. Distribution Statement Unclassified - Unlimited Subject Category 18		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of pages 8	
				22. Price* A02	